Jet Propulsion Laboratory
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SOME THOUGHTS ABOUT NUCLEAR POWER FOR MARS EXPLORATION

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THE INTERPLANETARY RTG FLEET

SNAP-27: Apollo 12-17

SNAP-19: Pioneer 10/11 (4 ea), Viking 1 & 2 (2 ea)

MMRTG: MSL-Curiosity, Mars 2020

MHW-RTG: VGR-1 & 2 (2 ea)

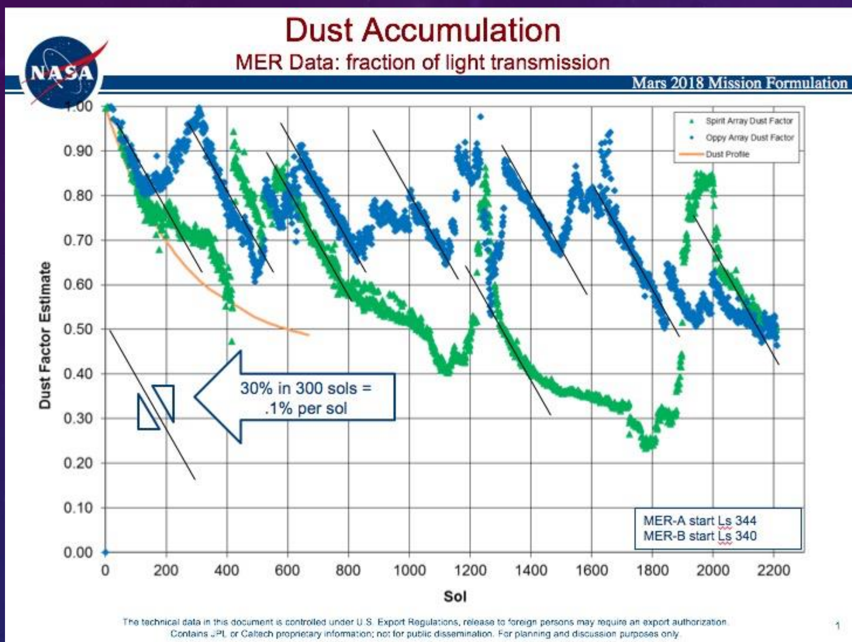
GPHS-RTG: GLL (2), Ulysses, Cassini(3), Pluto New Horizons

RTG Fleet | Solar | Thermal | ISRU | Water Mining | Role of Hydrogen | Closing

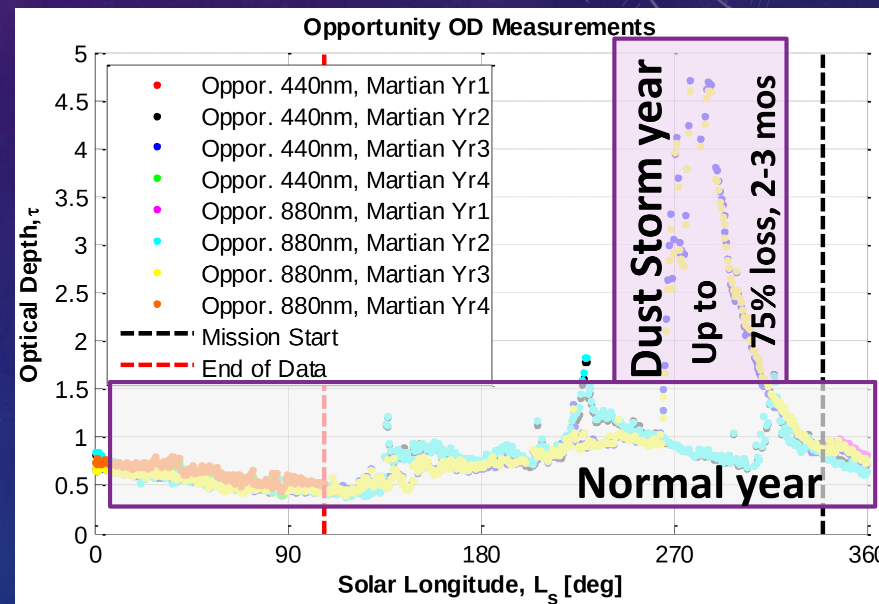
LIMITATION OF SOLAR POWER ON THE MARTIAN SURFACE

1) Dust Accumulation – Can Mitigate

MER: Routinely lose ~30% over 300 sol Period (1% / 10 sols)



2) Dust Storm Attenuation – Impractical to mitigate by oversizing; need storage to "weather through" (Batteries? Chemical?)



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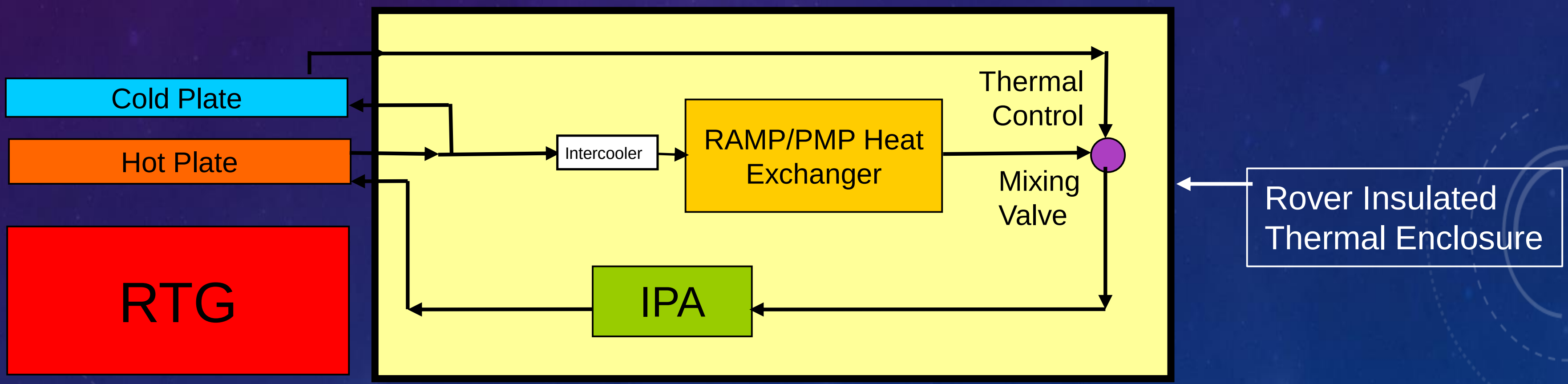
THERMAL ENERGY : LIABILITY OR ASSET?

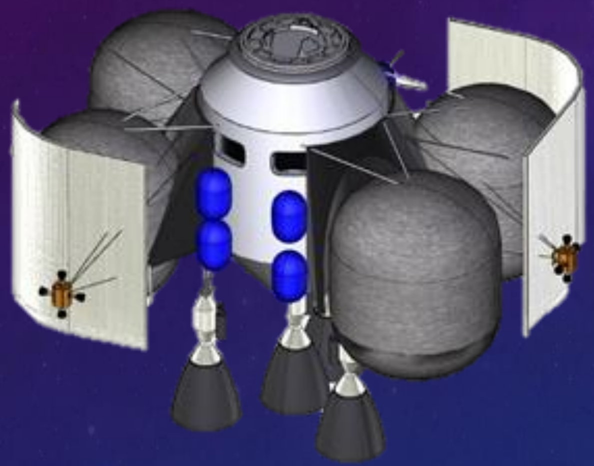
- In general, thermal energy conversion efficiency is desirable (less "waste" heat to reject) – but for several surface applications, heat energy can be just as valuable as electrical energy (also, see later discussion of water mining on Mars)

Pumped Fluid Thermal Management Schematic for Curiosity Rover



IN SITU RESOURCE UTILIZATION – LOX/METHANE (1 OF 2): A DIFFERENT KIND OF "ELECTRIC PROPULSION"?

Mars Ascent Vehicle (6 crew)



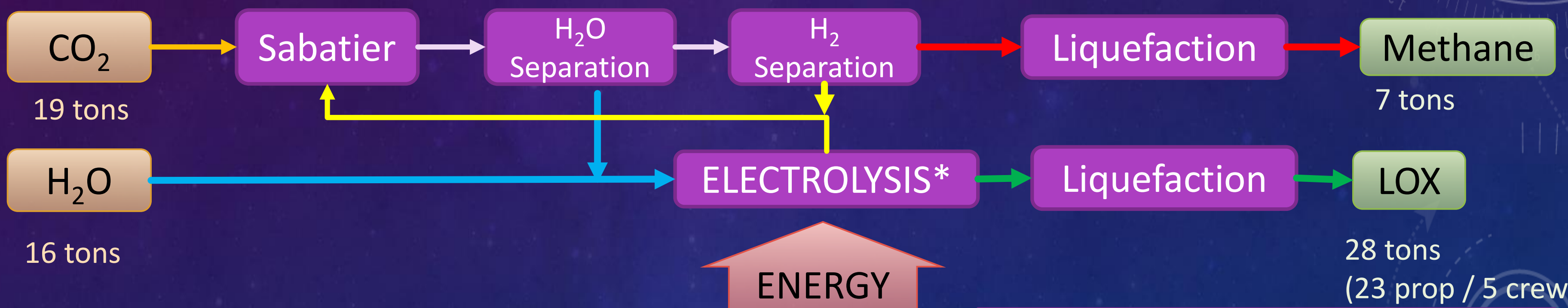
Artists concept Courtesy: NASA MSFC/JSC

Dry Mass: ~15,000 kg
Orbital Velocity: 5,000 m/s
Equivalent Energy: 190 Giga-joules / 53 MW-hrs
Rocket Efficiency: ~50%
Methane Energy: 55 Mega-joules/kg
Methane Required: ~7,000 kg

IN SITU RESOURCE UTILIZATION – LOX/METHANE (2 OF 2): A DIFFERENT KIND OF "ELECTRIC PROPULSION"?

LOX/METHANE PRODUCTION ON MARS

(Masses per 6 crew mission)



***Dominant Energy Process**

~500 days production time available between missions – 20-30 kW required (inc. thermal losses)

Courtesy: NASA GRC/JSC

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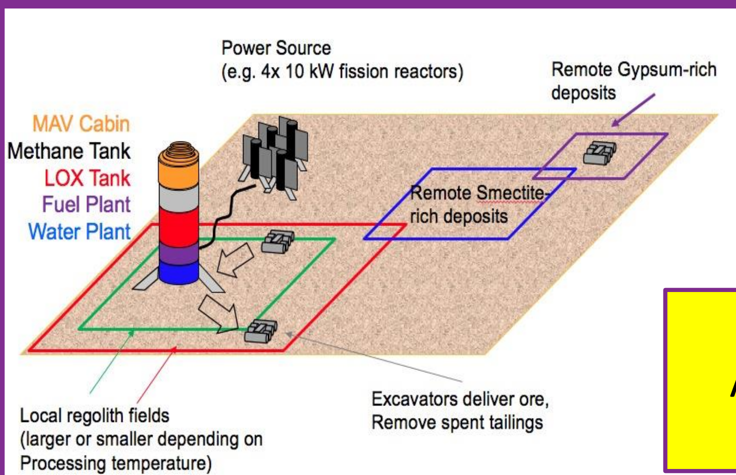
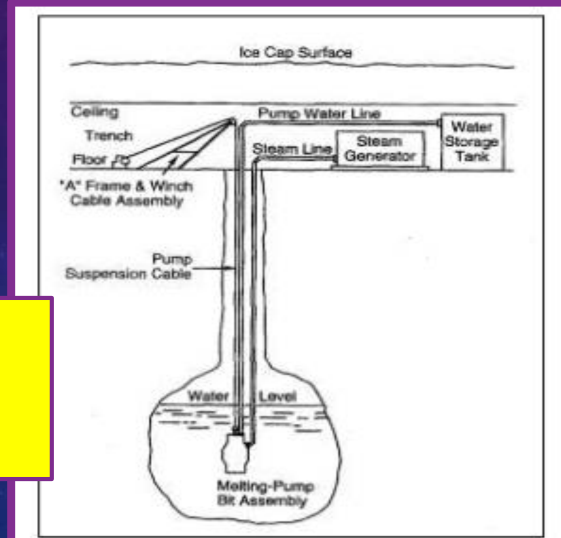
WATER MINING ON MARS: TWO STRATEGIES – ONE COMMON ENABLER

Harvest & bake hydrated mineral regolith at surface



Drill, melt, and recover Sub-surface ice



Either strategy requires ADDITIONAL ~10-20 kW (local or remote)

Abbud-Madrid, A, et al. Mars Water In-Situ Resource Utilization (ISRU) Planning (M-WIP) Study, April, 2016, http://mepag.nasa.gov/reports.cfm.

Lunardini, V.J. and J. Rand (1995). Thermal Design of an Antarctic Water Well. CRREL Special Report 95-10.

THE HYDROGEN ECONOMY ON MARS: TRANSPORTABLE COMPANION TO POWER GENERATION INFRASTRUCTURE

Mass: ~7,000 kg (Mars gravity = 3/8 earth)
Rolling friction: ~8% (Average terrain)
Reference Speed: 5 m/s (11 mph – 18 km/hr)
Rolling Power: 10 kW
Distance Energy: 2 MJ/km

Closed Loop Regenerative Fuel Cell?

Hydrogen: 142 MJ/kg, BUT 10 MJ/m^3 (LH_2)

10 km roundtrip range -> 1.5 m^3 of H_2
100 km roundtrip range -> **15 m^3** of H_2**!**

Pressurized Crew Rover

Artists concept Courtesy: NASA MSFC/JSC

SUMMARY - CLOSING THOUGHTS:

- RTG: Track record, Well-defined set of applications, Mature technology, potential evolution higher-efficiency conversion technologies

- Kilo-power Fission (with Stirling Conversion): Looks very promising for human exploration (including large-scale robotic precursors) for either Mars or the moon. Recommended primary focus area for R&D. Explore opportunities to make excess process heat available for applications that can capitalize on it (pumped fluid systems)

- Should also encourage synergistic work with fuel cells (ideally close—loop, regenerative) using hydrogen (or, if feasible, methane). Need to pay attention to masses, volumes, densities, for mobile applications.